Natural variations of δD and $\delta^{18}O$ in groundwater as a proxy for the isotopic composition of precipitation in Finland

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Studies of shallow groundwater in temperate climates have shown that the isotope ratios of hydrogen and oxygen closely represent the local mean annual precipitation (Clark and Fritz, 1997). The isotope values of precipitation, in turn, are linearly related to the annual mean temperature, especially in middle and high latitudes (Dansgaard, 1964). The results of a recent long-term groundwater monitoring program suggested that such a correlation is also characteristic to groundwaters in Finland (Backman et al., 1999). The data from another groundwater sampling program covering nearly 1000 wells seem to confirm the pattern. No systematic studies on the isotopic composition of precipitation in Finland have been published and this groundwater data therefore will give us the first approximation of regional variations in the isotopic composition of precipitation.

This paper will represent and combine data from two separate studies: a long-term monitoring of groundwater during 1995 - 1999 and a groundwater sampling program carried out during the summer of 1999. The former data consist of 16 shallow groundwater study sites sampled four times a year. All samples were analysed for $\delta^{18}O$ and δD. The latter data set consists mostly of shallow groundwaters but some deep groundwaters in drilled bedrock wells were also included. Altogether, 980 groundwater sites with a good geographical coverage were sampled. Isotopic composition of oxygen was analysed from all samples and that of hydrogen from 113 samples. No systematical differences in isotopic ratios were observed between shallow and deep groundwaters.

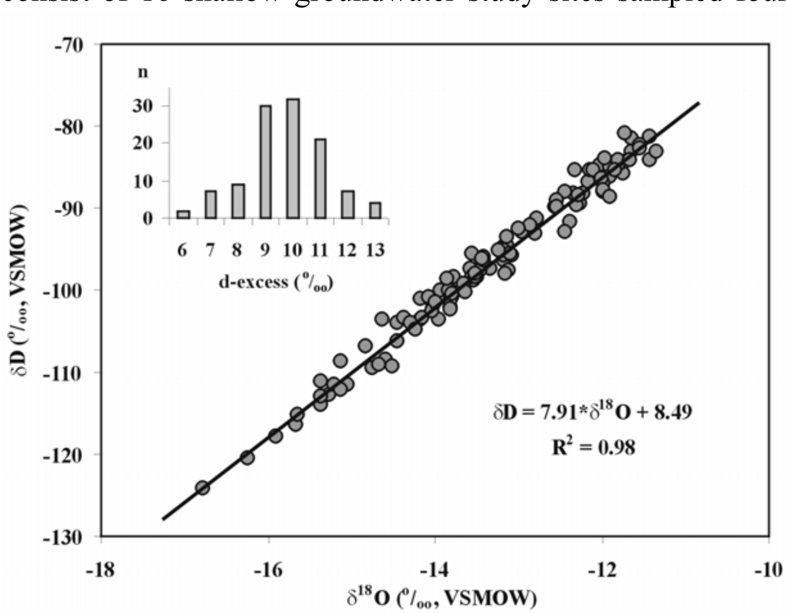

Figure 1. The δD-$\delta^{18}O$ relationship for groundwaters in Finland based on the regional data set (113 points). The inset shows the deuterium excess values as a frequency histogram (d-excess = δD – 8*$\delta^{18}O$).

The results of the long-term groundwater monitoring program confirm that seasonal fluctuations in isotope ratios are

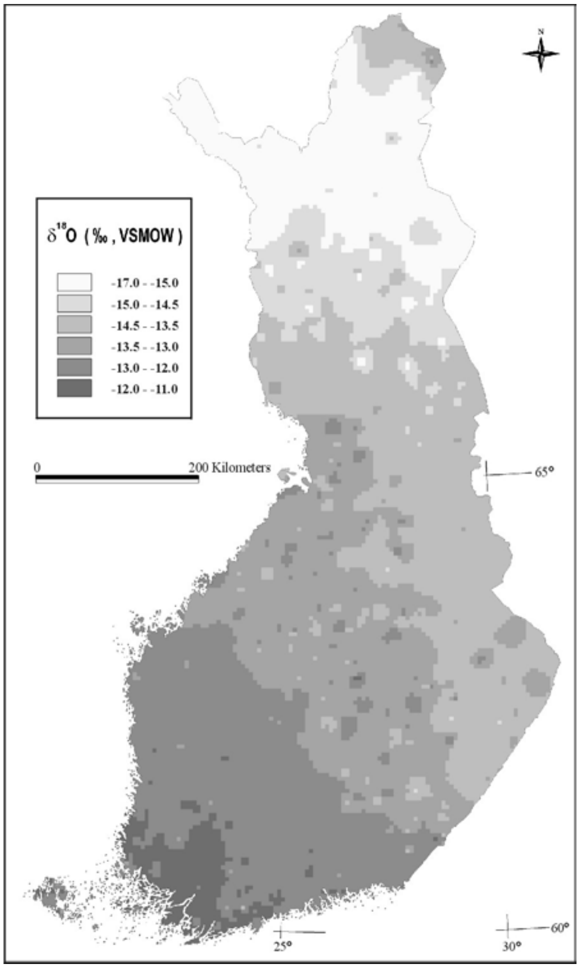

Figure 2. The distribution of the isotopic composition of oxygen in groundwaters from dug wells and drilled bedrock. The data, composed of 980 analyses, have been smoothed by IDW (Inverse Distance Weighted) interpolator using 100 km radius.

generally less than 0.5 ‰ in $\delta^{18}O$ and 4 ‰ in δD respectively. Fig. 1 shows the relationship between the $\delta^{18}O$ and δD values based on the regional data. The data points are highly correlated and yield a line, $\delta D = 7.9\ \delta^{18}O + 8.5$. The relationship is almost identical to that of the Global Meteoric Water Line (Dansgaard, 1964). The $\delta^{18}O$ values of groundwater range from -11.3 ‰ recorded in southern Finland, to –16.8 ‰ (VSMOW) in northern Finland and the δD values from –81 ‰ to –124 ‰ (VSMOW) respectively. The depletion in heavy isotopes is systematic and gradual from south to north (Fig. 2). In northernmost Finland there appears to be an inversion of isotope ratios towards more positive values. Apart from eastern Finland, the isotope shift occurs parallel with a change in mean annual surface temperature from +5ºC in the south to -3ºC in the north. The temperatures are interpolated using measurements of the closest meteorological stations. The oxygen isotope values based on the long-term monitoring data correlate linearly with mean annual temperatures defining a line with an equation $\delta^{18}O = 0.54 * t - 14.37$ (t = temperature, ºC) (Fig. 3). The slope of the line, 0.54 ‰ / ºC, is very close to that for $\delta^{18}O$ of precipitation and mean annual temperature in European stations reported by Rozanski et al. (1992). For those stations in IAEA/ WMO network the slope is 0.59 ‰ / ºC.

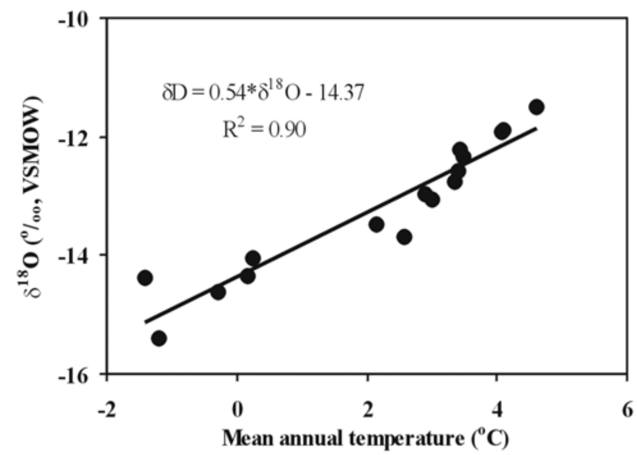

Figure 3. The correlation of $\delta^{18}O$ and mean annual temperature based on the data from the long-term groundwater monitoring program.

It can be concluded that mean annual temperature is the main factor controlling the isotopic composition of oxygen and hydrogen of shallow groundwater in Finland. The geographical position of Finland between the 60th and 70th northern parallels is exceptional compared to other areas in these latitudes. The annual mean temperature is raised by warm airflows from the

Atlantic, warmed by the Gulf Stream. In addition, temperature variations are attenuated by the large volume of water in the Baltic Sea and inland lakes as well as the Barents Sea in the north. The precipitation is mainly derived from one vapour source in the North Atlantic Ocean. Re-evaporation of water from the Baltic Sea and large lakes in southern Finland and the Barents Sea in the northern Finland may potentially influence the isotope ratios of precipitation. However, no regional variations can be observed in deuterium excess of groundwaters. The distribution of the d-excess values, calculated for individual data points, is narrow, ranging from 9 ‰ to 11 ‰ in 73 percent of the regional data (Fig. 1) and from 8 ‰ to 10 ‰ in all long-term monitoring sites.

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